

ART. VII.—THE TELEPHONE.

OF all modern inventions connected with the transmission of telegraphic signals, the telephone, devised by Mr. Alexander Graham Bell, has excited the most wide-spread interest and wonder. Wherever Mr. Bell has appeared before the public to give an account of his invention and the researches which have led up to it, crowds have assembled to hear him. Nor is this astonishing; for the telephone professes not only to convey intelligible signals to great distances without the use of a battery, but to transmit in facsimile the tones of the human voice, so that a voice shall be as certainly recognised when heard over a distance of a few hundreds of miles as if its owner were speaking in the room by our side. And the telephone does not fall short of its profession. Scientific men have had their wonder and curiosity aroused even more than the unscientific public, since a scientific man appreciates the enormous difficulties to be overcome before such an instrument can be realised. Had any hardy speculator a few years ago proposed a telephone which should act on the principle, and be constructed in the form, of Mr. Bell's instrument, he would probably have been considered a lunatic. The effects are so marvellous; the exciting causes at first sight so entirely inadequate to produce them. For a telephonic message differs as widely from an ordinary telegraphic message as a highly finished oil-painting differs from a page of print. In the one you have only white and black, black symbols on a white ground, the symbols being limited in number, and recurring again and again with mere differences of order. The painting, on the other hand, discloses every variety of colour and arrangement. No sharp lines of discontinuity offend the eye; on the contrary, the tints shade off gradually and softly into each other, presenting tone and depth in endless variety. The page of print is unintelligible without the aid of a key; the painting tells its story plainly enough to any one who has eyes to see.

Let us inquire for a moment what is the nature of the apparatus which we have been using for the last thirty or forty years for the transmission of telegraphic signals. The instruments chiefly employed have been the single-needle telegraph and the Morse instrument. In the former a coil of wire surrounds a magnetised needle, which is suspended in a vertical

position. When an electrical current passes through the coil, the needle is deflected, to right or left, according to the direction of the current. The sender by means of a handle can pass either positive or negative currents into the circuit. The right and left deflections of the needle are combined in various ways to form the letters of the alphabet, and the letters form words. Thus at the sending station a message is broken up into little bits, each bit or part of a bit transmitted separately, and the process of building these up again performed at the receiving station. Some of the letters of the alphabet are indicated by a single movement of the needle, that is, by a single current ; for others, as many as four are required.

In the Morse instrument only one current is utilised, which may be either positive or negative, and the requisite variety is obtained by allowing the current to pass through the circuit for a longer or shorter interval. The essential part of the instrument consists of an electro-magnet with an iron armature attached to one end of a lever. At the other end of the lever is a pointer or pencil, and a paper ribbon moves at a constant rate in front of the end of the pointer. When the coils of the electro-magnet are traversed by a current, the iron armature is attracted, and the pointer comes in contact with the paper ribbon, on which it makes a mark, long or short, according to the duration of the current. Thus are produced the dots and dashes. These are combined in a similar way to the right and left movements of the needle in the needle instrument. In some of the more refined instruments letters are indicated and even printed directly at the receiving station. This is of course a great simplification ; but with such arrangements we cannot have more than this. The page of print represents the limit of what such instruments and methods can do for us. It is true that a skilled operator with the Morse instrument can interpret the signals as they arrive without looking at the marks on the paper, simply by using his ears. Every time the circuit is made or broken a click is heard, and long practice has taught him to rely on the evidence of his ears with as much confidence as one less accustomed to the work would trust his eyes. Nevertheless he hears only a succession of clicks, which must be interpreted before they become intelligible to any one but himself.

In these forms of apparatus, it will be observed, the currents are intermittent ; each current, circulating through the coil, is followed by an interval of rest. They begin and end abruptly, and all perform the same kind of work ; that is, they deflect a needle, or produce marks on a piece of paper. Telephonic currents, on the other hand, rise and fall, ebb and flow, change in

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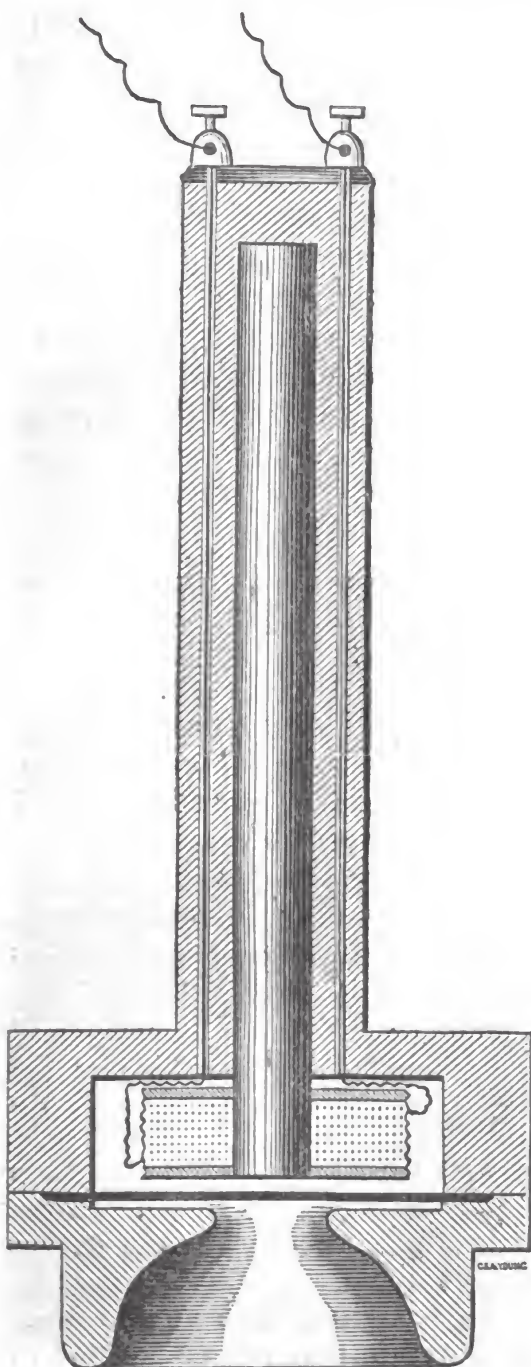
intensity within comparatively wide limits, but preserve their continuity so long as continuous sounds are being uttered in the neighbourhood of the telephone. They are called undulatory currents, to distinguish them from the intermittent currents of the ordinary telegraphic apparatus; and their peculiar character is an essential feature of the telephone.

No skill or training is required for the effective use of the telephone. The operator has merely to press the instrument to his ear to hear distinctly every sound transmitted from the distant end. For this, it is true, an effort of attention is required, and some persons use the instrument at the first trial with more success than others. Individuals differ in the facility with which they are able to concentrate their attention on one ear, so as to be practically insensible to what goes on around them. But this habit of attention is readily acquired, and when it is once acquired, the telephone may be used by any one who has ears to hear and a tongue to speak. In sending a message, the instrument is held about an inch in front of the mouth, and the sender merely talks into the mouth-piece in his ordinary natural manner. The words are repeated by the instrument at the other end of the circuit with the same pitch, the same cadences, and the same relative loudness. But what strikes one the most is that the *character* of the speaker's voice is faithfully preserved and reproduced. Thus one voice is readily distinguished from another. No peculiarity of inflection is lost. Nor is this result effected over short distances only. No doubt a sentence will be heard with diminishing distinctness as it comes over an increasing distance. In this country experiments have not yet been made, so far as we know, over very long distances; but Mr. Bell states that he carried on a conversation without any difficulty between Boston and New York, 258 miles apart, through an ordinary telegraph wire. A man's breathing was distinctly heard 149 miles away. At the Newport torpedo station, in Rhode Island, speaking was carried on through a line, including five miles of submerged cable and an equal length of land wire. Resistance coils were added, 2000 ohms at a time, until 12,000 ohms were introduced into the circuit, without interfering with the transmission of speech. The importance of this test will be understood when it is remembered that the resistance of the Atlantic cable is equal to 7000 ohms only. The experiments at Newport were continued by the addition of a total resistance of 30,000 ohms, but beyond 12,000 ohms the sound was found to diminish in intensity. Mr. Bell states that the *maximum* amount of resistance through which the undulating current will pass, and yet retain sufficient force to produce an audible sound at the distant end,

has yet to be determined. In the laboratory he has conversed through a resistance of 60,000 ohms. There is a practical difficulty in transmitting telephonic signals through a telegraph wire running parallel to a number of other wires which are being used for ordinary telegraphic purposes. Induction currents are produced in the telephone wire, which greatly interfere with the distinctness of the sounds. This difficulty is said to be overcome by having an extra return wire, instead of utilising the earth for a part of the circuit, as is ordinarily done. The two wires are put side by side in close proximity, and the detrimental effect of the inductive currents is thus partially or entirely disposed of. The following extract from a letter which appeared in the *Daily News* a few weeks ago shows that inductive action, when the parallel circuits are not numerous, does not seriously interfere with the transmission of speech:—

“The experiments with the telephone were made by me upon the cable lying between Dover and Calais, which is $21\frac{3}{4}$ miles long. Several gentlemen and ladies were present, and conversed in French and English with a second party in France for upwards of two hours. There was not the slightest failure during the whole time. I was only using one wire. The other three (it is a four-wire cable) were working direct with London and Paris, Calais and Lille. I could distinctly hear the signals by the three wires on the telephone; and at times, when but one of the three wires was working, I could decipher the Morse signals, and read a message that was passing from Glasgow to Paris. Yet when all the three wires were working simultaneously, the telephone sounds were easily and clearly distinguishable above the click of the signals! I happened to know several of the party in France, and was able to recognise their voices. They also recognised mine, and told us immediately a lady spoke that it was a female voice. When making some trials upon a line three-fourths of a mile long, I arranged a musical box (the tones of which are very feeble) under the receiver of an air-pump, the top of the receiver being open. Upon this opening I placed the telephone, and every note came out at the second end so clearly as to enable those who were present to name the tune that was played. Unfortunately we had not the same means in France, but simply held the mouth of the telephone close to the box, and some of the notes were audible, but not so perfect as on the short line. One young lady burst out laughing the moment she placed the instrument to her ear, and exclaimed, ‘Some one is whistling “Tommy make way for your uncle!”’ As my correspondent and myself had had a little practice, we were, without the slightest difficulty, able to talk in our usual manner, without any strain upon the voice or any unnatural lengthening of syllables. We were not able to hear breathing, in consequence of the continued pecking caused by induction from other wires.”

The construction of the telephone is remarkably simple, and will be readily understood from the accompanying woodcut, which



represents a longitudinal section. It consists of a steel cylindrical magnet, about five inches long and three-eighths of an inch in diameter, encircled at one extremity by a short bobbin of wood or ebonite, on which is wound a quantity of very fine insulated copper wire. The magnet and coil are contained in a wooden cylindrical case. The two ends of the coil are soldered to thicker pieces of copper wire, which traverse the wooden envelope from one end to the other, and terminate in the binding screws at its extremity. Immediately in front of the magnet is a thin circular iron plate, which is kept in its place by being jammed between the main portion of the wooden case, and a wooden cap carrying the mouth or ear-trumpet. These two parts are screwed together. The latter is cut away at the centre so as to expose a portion of the iron plate, about half-an-inch in diameter. In the experiments which Mr. Bell has carried out in order to determine the influence of the various parts of the telephone on the

results produced, and their relations to each other when the best effects are obtained, he employed iron plates of various areas and thicknesses, from boiler plate three-eighths of an inch in thickness to the thinnest plate procurable. Wonderful to relate, it appears that scarcely any plate is too thin or too thick for the purpose, but the best thickness is that of the ferrotype plate used by photographers. Thin tin-plate also answers very well. The iron plate is cut into the form of a disc, about two inches in diameter, and is placed as near as

possible to the extremity of the steel magnet without actually touching it; the effect of this position being that, while the induced magnetism of the plate is considerable, it is susceptible to very rapid changes owing to the freedom with which the plate can vibrate. The dimensions of the various parts of the instrument given above are found to be convenient, but they are by no means essential. Good results have been obtained by means of a magnet only an inch and a half long, and a working instrument need not be too large for the waistcoat pocket. There is no difference between the transmitting and the receiving telephone; each instrument serves both purposes. Nevertheless in order to avoid the inconvenience of shifting the instrument backwards and forwards between the ear and the mouth, it is better to have two on the circuit at each station. The operator then holds one permanently to his ear, while he talks with the other.

It will not be supposed that the idea of this marvellously simple piece of apparatus was evolved ready formed from the inventor's brain; very far otherwise. It is the final outcome of a long series of patient researches carried out by Mr. Bell in the most skilful and philosophical manner, in which one modification suggested another, accessory after accessory was discarded, and finally the instrument was pruned down to its present form and dimensions. Telephones have been long known. A few years ago a simple arrangement whereby articulate sounds could be transmitted over a distance of fifty or sixty yards, or even further, could be bought in the streets for a penny. It consisted of a pair of pill boxes, the bottoms of which were connected by a piece of string stretched tight, while over the mouth of each was pasted tissue paper. On speaking to one of the pill boxes the tissue paper and enclosed air were set in vibration. The vibrations so produced were communicated to the thread and transmitted to the distant pill box, which was held close to the ear, where they affected the air in such a way as to reproduce the original sounds. This simple apparatus was more effective than would be *à priori* imagined. Electric telephones were devised in this country about the same time that the telegraph was introduced, but the best of them differed widely from the modern instrument. They were capable of conveying to a distance sounds of various pitch, so that the succession of notes constituting a melody could be reproduced many miles away, but the special character of the voice by which the melody was originated was entirely lost. Now the great interest which attaches to Mr. Bell's telephone, and the intense wonder and curiosity it has aroused, are due to its power of conveying absolutely unaltered every peculiarity of voice or musical instrument. A violin note reappears as a violin note; it cannot

be mistaken for anything else. And in the case of a human voice, it is not less easy to distinguish one speaker from another than it would be if the speakers were in the room close by instead of being miles or even hundreds of miles away. This is the charm of the new telephone ; this it is which renders it immeasurably superior to anything of the kind which preceded it.

Mr. Bell's researches in electric telephony began with the artificial production of musical sounds, suggested by the work in which he was then engaged in Boston, viz., teaching the deaf and dumb to speak. Deaf mutes are dumb merely because they are deaf. There is no local defect to prevent utterance, and Mr. Bell has practically demonstrated by two thousand of his own pupils that when the deaf and dumb know how to control the action of their vocal organs, they can articulate with comparative facility. Striving to perfect his system of teaching, it occurred to Mr. Bell that if, instead of presenting to the eye of the deaf mute a system of symbols, he could make visible the vibrations of the air, the apparatus might be used as a means of teaching articulation. In this part of his investigations Mr. Bell derived great assistance from the phonautograph. He succeeded in vibrating by the voice a style of wood, about a foot in length, attached to the membrane of the phonautograph ; and with this he obtained enlarged tracings of the vibrations of the air, produced by the vowel sounds, upon a plane surface of smoked glass. Mr. Bell traced a similarity between the manner in which this piece of wood was vibrated by the membrane of the phonautograph and the manner in which the ossiculæ of the human ear were moved by the tympanic membrane. Wishing to construct an apparatus closely resembling the human ear, it was suggested to him by Dr. Clarence J. Blake, a distinguished aurist of Boston, that the human ear itself would be still better, and a specimen was prepared. Our readers are aware that the tympanic membrane of the ear is connected with the internal ear by a series of little bones called respectively the malleus, the incus, and the stapes, from their peculiar shapes, and that by their means the vibrations of the tympanic membrane are communicated to the internal ear and the auditory nerves. Mr. Bell removed the stapes, and attached to the end of the incus a style of hay about an inch in length. Upon singing into the external artificial ear, the style of hay was thrown into vibration, and tracings were obtained upon a plane surface of smoked glass passed rapidly underneath. The curves so obtained are of great interest, each showing peculiarities of its own dependent upon the vowel sound that is sung. Whilst engaged in these experiments, Mr. Bell's attention was arrested by observing the wonderful disproportion which exists between the size and

weight of the membrane—no thicker than tissue paper—and the weight of the bones vibrated by it, and he was led to inquire whether a thicker membrane might not be able to vibrate a piece of iron in front of an electro-magnet. The experiment was at once tried. A piece of steel spring was attached to a stretched membrane of gold-beater's skin and placed in front of the pole of the magnet. This answered very well, but it was found that the action of the instrument was improved by increasing the area of metal, and thus the membrane was done away with and an iron plate substituted for it. It was important, at the same time, to determine the effect produced by altering the strength of the magnet; that is, of the current which passed round the coils. The battery was gradually reduced from fifty cells to none at all, and still the effects were observed, but in a less marked degree. The action was in this latter case doubtless due to residual magnetism; hence, in the present form of apparatus a permanent magnet is employed. Lastly, the effect of varying the dimensions of the coil was studied, when it was found that the sounds became louder as its length was diminished; a certain length was, however, ultimately reached, beyond which no improvement was effected, and it was found to be only necessary to enclose one end of the magnet in the coil of wire.

Such was the instrument that Mr. Bell sent to the Centennial Exhibition at Philadelphia. The following is the official report of it, signed by Sir William Thomson and others:—

“Mr. Alexander Graham Bell exhibits an apparatus by which he has achieved a result of transcendent scientific interest,—a transmission of spoken words by electric currents through a telegraph wire. To obtain this result Mr. Bell perceived that he must produce a variation of strength of current as nearly as may be in exact proportion to the velocity of a particle of air moved by the sound, and he invented a method of doing so,—a piece of iron attached to a membrane, and thus moved to and fro in the neighbourhood of an electro-magnet,—which has proved perfectly successful. The battery and wire of this electro-magnet are in circuit with the telegraph wire and the wire of another electro-magnet at the receiving station. This second electro-magnet has a solid bar of iron for core, which is connected at one end by a thick disc of iron to an iron tube surrounding the coil and bar. The free circular end of the tube constitutes one pole of the electro-magnet, and the adjacent free end of the bar core the other. A thin circular iron disc, held pressed against the end of the tube by the electro-magnetic attraction and free to vibrate through a very small space without touching the central pole, constitutes the sounder by which the electric effect is reconverted into sound. With my ear pressed against this disc, I heard it speak distinctly several sentences. . . . I

need scarcely say I was astonished and delighted. So were others, including some judges of our group, who witnessed the experiments and verified with their own ears the electric transmission of speech. This, perhaps the greatest marvel hitherto achieved by the electric telegraph, has been obtained by appliances of quite a homespun and rudimentary character. With somewhat more advanced plans and more powerful apparatus, we may confidently expect that Mr. Bell will give us the means of making voice and spoken words audible through the electric wire to an ear hundreds of miles distant."

The present form of instrument which is now being manufactured in large numbers by the Silvertown Company does not essentially differ from that reported on so enthusiastically by Sir William Thomson. Only it is more simple in construction and more handy.

Before attempting any explanation of the action of the telephone it may be well to draw the attention of our readers to the special characteristics of the human voice, and to those peculiarities which distinguish one musical note from another. Whatever the differences in question may depend upon, it is certain that they are transmitted and reproduced in the telephone with unerring fidelity, and it is therefore important that we should understand their nature and origin. Take a tuning-fork and set it in vibration by striking or drawing a violoncello bow across its prongs. The fork yields its own proper note, which will be loud or the reverse according as the fork has been struck energetically or lightly. So long as we use one fork only, it is obvious that the only variation which can be produced in the sound is a variation of intensity. If the extent of vibration be small, the resulting sound is feeble; its loudness increases with the excursion of the prongs. What is true of the tuning-fork is true of any other musical instrument, and hence, generally, the loudness of a musical sound depends upon the amplitude of vibration of that which produced it. Now take two similar tuning-forks of different pitch, and suppose that one is exactly an octave above the other. They may be excited in such a way that the notes emitted are of equal loudness, and then the only respect in which they differ from each other is in pitch. The pitch of a fork depends upon its rate of vibration. It is comparatively easy with suitable apparatus to measure the rate of vibration of a tuning-fork, and were we to test the two forks in question, it would be found that that giving the higher note vibrates exactly twice as fast as the other. If the one performs 100 oscillations in a second, the other, which is an octave above, completes 200 in the same interval of time. Thus, the pitch of a note yielded by a tuning-fork depends upon its rate of vibration, and on nothing else, and the same is true of a pianoforte wire, the air in an

organ pipe, a harmonium reed, &c. We have now accounted for two of the characteristics of a musical note, its loudness and its pitch; but there is a third, equally, if not more, important, and by no means so simple of explanation. We refer to what is usually spoken of in English books on acoustics as the *quality* of the note; the French call it *timbre*, and the Germans *klangfarbe*. It is that which constitutes the difference between a violin and an organ, or between an organ and a pianoforte, or between two human voices; indeed between any two musical sounds which are of the same pitch and loudness, but are still distinguishable from each other. In order to explain the physical cause of *quality*, we will suppose we have a thin metallic wire about a yard long stretched between two points over a sounding board. When plucked at its centre the wire vibrates as a whole; the two ends are points of rest, and a loop is formed between them. The note emitted by the wire when vibrating in this manner is called its fundamental note. If the wire be damped at the centre, by laying on it with slight pressure the feather of a quill pen, and plucked at a point half way between the centre and one end, both halves will vibrate in the same manner, and independently of each other. That is to say, there will be two equal vibrating segments and a point of rest or node at the centre. But the rapidity of vibration of each segment will be twice as great as that of the wire when vibrating as a whole, and consequently the note emitted will be the octave of the fundamental. When damped at a point one-third of the length from either extremity, and plucked half way between that point and the nearer extremity, the wire will vibrate in three equal divisions, just as it vibrated in two divisions in the previous case. The rate of vibration will be now three times as great as at first, and the note produced will be a twelfth above the fundamental. Similarly, by damping and plucking at suitable points, the wire may be made to vibrate in four parts, five parts, six parts, &c., the rate of vibration increasing to four, five, six, &c., times what it was at first. Let us suppose that when the wire was swinging as a whole and sounding its fundamental note, the number of oscillations performed in a second was 100. Then we see that, by taking suitable precautions, the wire can be made to break up into two, three, four, five, six, &c., vibrating segments, the rates of vibration being respectively 200, 300, 400, 500, 600, &c., and the series of notes emitted being the octave above the fundamental, the fifth above the octave, the double octave, the third and fifth above the double octave, and so on. We now come to an important point, which is this—that, the wire being free, it is practically impossible to strike or pluck it in such a way as to make it vibrate according to one of the above systems *only*. It

will vibrate as whole, wherever and however it be struck, but this mode has always associated with it or superposed upon it some of the other modes of vibration to which we have just referred. In other words, the fundamental note is never heard alone, but always in combination with a certain number of its overtones, as they are called. Each form of vibration called into existence sings as it were its own song, without heeding what is being done by its fellows, and the consequence is that the sound which reaches the ears is not simple but highly composite in its character. The word *clang* has been suggested to denote such a composite sound, the constituent simple sounds, of which it is the aggregate, being called its first, second, third, &c., partial-tones. All the possible partial-tones are not necessarily present in a clang, nor of those which are present are the intensities all the same. For instance, if the wire be struck at the centre, that point cannot be a node, but must be a point of maximum disturbance; hence all the even partial-tones are excluded, and only the odd ones, the first, third, fifth, and so on, are heard.

That characteristic of a musical note or clang which is called its quality, depends upon the number and relative intensities of the partial-tones which go to form it. The tone of a tuning-fork is approximately simple; so is that of a stopped wooden organ pipe of large aperture blown by only a slight pressure of wind. Such tones sound sweet and mild, but also tame and spiritless. In the clang of the violin, on the other hand, a large number of partial-tones are represented; hence the vivacious and brilliant character of this instrument. The sounds of the human voice are produced by the vibrations of the vocal chords, aided by the resonance of the mouth. The size and shape of the cavity of the mouth may be altered by opening and closing the jaws, and by tightening or loosening the lips. We should expect that these movements would not be without effect on the resonance of the contained air, and such proves on experiment to be the fact. Hence, when the vocal chords have originated a clang containing numerous well-developed partial-tones, the mouth cavity, by successively throwing itself into different postures, can favour by its resonance first one overtone and then another; at one moment *this* group of partial-tones, at another *that*. In this manner endless varieties of quality are rendered possible. Any one may prove to himself, by making the experiment, that when singing on a given note he can only change from one vowel sound to another by altering the shape and size of his mouth cavity.

Having thus briefly indicated the physical causes of the various differences in musical notes, and the production of sounds by the organ of voice, we will devote a few moments to consider how these sounds are propagated through the air and reach the plate

of the telephone. When a disturbance is produced at any point in an aerial medium, the particles of which are initially at rest, sonorous undulations spread out from that point in all directions. These undulations are the effect of the rapid vibratory motions of the air particles. The analogy of water waves will help us to understand what is taking place under these circumstances. If a stone be dropped into the still water of a pond, a series of concentric circular waves is produced, each wave consisting of a crest and a hollow. The waves travel onwards and outwards from the centre of disturbance along the surface of the water, while the drops of water which constitute them have an oscillatory motion in a vertical direction. That is to say, following any radial line, the water particles vibrate in a direction at right angles to that in which the wave is propagated. The distance between two successive crests or two successive hollows is called the length of the wave; the amplitude of vibration is the vertical distance through which an individual drop moves. In a similar manner sonorous undulations are propagated through air by the oscillatory motion of the air particles. But there is this important difference between the two cases, that, in the latter, the vibrating particles move in the *same* direction in which the sound is being propagated. Consequently such waves are not distinguished by alternate crests and hollows, but by alternate condensations and rarefactions of the air, the transmission of which constitutes the transmission of sound. The wave-length is the distance between two consecutive condensations or rarefactions. It depends upon the pitch of the transmitted sound, being shorter as the sound is more acute, while the extent of vibration of the air particles increases with the loudness. Such are the peculiarities of the vibratory motion in air corresponding to the pitch and loudness of the transmitted sound. But what is there in the character of the motion to account for difference in quality? A little consideration will show that there is only one thing left to account for these, and that is the *form* of the vibration. Let us mentally isolate a particle of air, and follow its movements as the sound passes. If the disturbance is a simple one, produced, say, by the vibration of a tuning fork, the motion of the air particle will be simple also, that is, it will vibrate to and fro like the bob of a pendulum, coming to rest at each end of its excursion, and from these points increasing in velocity until it passes its neutral point. Such, however, is clearly not the only mode of vibration possible. If the disturbance be produced by a clang comprising a number of partial-tones of various intensities, all excited simultaneously, it is obvious that the air particle must vibrate in obedience to every one of these. Its motion will be the resultant of all the motions due to the separate partial-

tones. We may imagine it, starting from its position of rest, to move forward, then stop short, and turn back for an instant, then on again until it reaches the end of its excursion. In returning it may perform the same series of to and fro motions in the opposite direction, or it may move in a totally different way. Nevertheless, however complex its motion may be—and, as a rule, it will be exceedingly complex—its periodic character will be maintained. All the tremors and perturbations in one wavelength will recur in all the others.

When sonorous undulations impinge upon the iron plate of the telephone, the latter is set in vibration. Its particles move to and fro in some way or other. The complexity of their motion will depend upon that of the air from which it was derived. But for the sake of simplicity we will assume that the plate has a simple pendulous motion. It will be remembered that the iron plate is placed quite close to, but not quite in contact with, the extremity of the steel magnet. It becomes, therefore, itself a magnet by induction; and, as it vibrates, its magnetic power is constantly changing, being strengthened when it approaches the magnetic core, enfeebled as it recedes. Again, when a magnet moves in the neighbourhood of a coil of wire, the ends of which are connected together, an electrical current is developed in the coil, whose strength depends upon the rapidity with which, and the distance through which, the magnet moves. In the telephone then, as the plate moves towards the coil, a current is induced in the latter which traverses the whole length of wire connecting it with the distant instrument; the plate returning, another current with reversed sign follows the first. The intensity of these currents depends, as we have said, on the rapidity with which these movements are effected, but is largely influenced also by the fact that the plate does not retain a constant magnetic strength throughout its excursions: Under the assumption we have made with respect to the simplicity of the plate's motion, it follows that the induced currents, alternately positive and negative, follow each other in a uniform manner, and with a rapidity corresponding to the pitch of the exciting note. These currents pass along the circuit, and circulate round the coil of the distant telephone. There they modify the magnetic relations between the steel magnetic core and the iron plate in such a way that one current—say the positive—attracts the plate, while the other—the negative—repels it. And since the arriving currents follow each other, first positive and then negative, with perfect regularity, the plate will also vibrate in a uniform manner, and will perform the same number of vibrations per second as did the plate of the sending instrument. Hence the sound heard will

be an exact copy, except as to loudness, of that produced at the sending station. Having thus followed the sequence of phenomena in this simple case, we are enabled to extend our explanation to the case in which composite sounds of more or less complexity—vowel sounds and speech—are transmitted. We are compelled to admit that every detail in the motion of an air particle, every turn and twist, must be passed on unaltered to the iron membrane, and that every modification of the motion of the membrane must have its counterpart in a modification of the induced currents. These, in their turn, affecting the iron plate of the receiving telephone, it follows that the plates of the two telephones must be vibrating in an absolutely identical manner.

We can thus follow in a general manner the course of the phenomena, and explain how air vibrations are connected with the vibrations of a magnetic plate—how these latter give rise to electrical currents, which, passing over a circuit of hundreds of miles, cause another magnetic plate to vibrate; every tremor in the first being reproduced in facsimile in the second, and thus excite sonorous undulations which pass on to the ear. We can understand all this in a general way, but we are not the less lost in wonder that the sequence of events should be what it is. That a succession of currents could be transmitted along a telegraph wire without the aid of a battery, that, by simply talking to a magnetic membrane in front of a coil of wire, the relations of the magnetic field between the two could be so far modified as to produce in the coil a succession of electrical currents of sufficient power to traverse a long circuit, and to reproduce a series of phenomena identical with those by which the currents were brought into existence, would have been a few years ago pronounced an impossibility. A man would have been derided who proposed an instrument constructed on such principles. Nevertheless, here it is realised in our hands. We can no longer doubt, we can only wonder, and admire the sagacity and patience with which Mr. Bell has worked out his problem to a successful issue.

